Digital Imagery for Works of Art

Harvard University Art Museums
Cambridge, Massachusetts

November 19 and 20, 2001

Sponsored by:

The Andrew W. Mellon Foundation
The National Science Foundation
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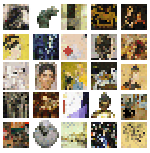

Report of the Co-Chairs:

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Professor of English
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Appendixes On-Line*

* http://www.dli2.nsf.gov/mellon/index.html

Preface

The motivation for this workshop came out of continuing discussions over the past several years between staff at the Andrew W. Mellon Foundation and National Science Foundation (NSF) regarding common interests in their program goals and the increasing complementarity between sponsored activities in several areas of computing and the humanities. These discussions led to speculation about how the NSF and the Mellon Foundation might coordinate funding activities to more effectively leverage their investments, while at the same time increasing the scope of programs and addressing new application areas.

Although the NSF has traditionally focused on the support of science and engineering and the Mellon Foundation on the arts and humanities, recent and dramatic advances in computing and communications have blurred the boundaries between traditional disciplinary lines, and altogether new classes of interdisciplinary research have emerged and taken hold in the academic community. Rapid improvements in the capabilities of computing and memory components in tandem with rapid growth in internet-based digital content and high bandwidth connectivity have made available to humanities researchers powerful new tools at an affordable cost. Many such researchers and their students, as well as collection curators and conservators have taken up and become fluent with new information technology and resources, and have become significant contributors of high quality content to the World Wide Web. Meanwhile, numerous research opportunities have emerged to extend even further the utility of leading edge information technologies.

The NSF, though its Digital Libraries Initiative, and the Mellon Foundation, through its various programs, each have sponsored several collaborative projects which apply and adapt these technologies to manage and analyze large and varied digital collections of humanities content.

Art history is now viewed by humanists and information technologists alike as a particularly promising area of joint inquiry in which computing and traditional humanities scholarly methods come naturally together. Scholars, students and researchers in the visual arts are increasingly interested in having access to digital images for analysis and study that push conventional boundaries in various humanistic disciplines. Similarly, creating, managing and delivering visual imagery for multiple purposes stretches computing and networking technologies in many different directions. Running through recent Digital Library Initiative projects, for example, are several persistent threads that highlight some of these research challenges, including the development of mechanisms for the retrieval of images based on visual content and issues related to the creation and maintenance of high-resolution two- and three-dimensional digital representations of art objects.

In light of these recent developments, the workshop on Digital Imagery for Works of Art was organized to bring together leading experts from the technology and visual arts domains to share knowledge and explore the potential of digital imagery research to

contribute to research in art history and closely related fields. At the same time, the participants were asked to identify new opportunities for research in digital imaging and related fields. An important goal was to identify and recommend particularly meritorious collaborative activities for potential joint funding by the Andrew W. Mellon and National Science Foundations.

We believe that the workshop accomplished all of these goals and more. We wish to thank all the participants for their contributions. We also wish to thank the Harvard University Art Museums for hosting the meeting.

We especially wish to thank, and are indebted to, the co-organizers: Kevin Kiernan, Charles Rhyne and Ron Spronk. Their effort in planning and organizing the meeting was essential to its successful outcomes and was indeed a model of the collaborative activity the workshop was meant to explore and promote. The workshop report they produced eloquently captures the substance of the two days of discussions, and lays out a clear path for NSF and the Mellon Foundation to follow in establishing new individual and joint funding programs in areas important to academic science, humanities and the arts, and to society as a whole.

Stephen M. Griffin, National Science Foundation
Donald Waters, Andrew W. Mellon Foundation

Summary

This workshop was called to explore how the research and development agenda of computing, information and imaging scientists might more usefully serve the research needs of art and architecture historians, art curators, conservators, and scholars and practitioners in closely related disciplines. At the same time, we looked for opportunities where applications in the art history domain might inform and push information technology research in new and useful directions.

Introduction

This invitational workshop was designed to bring together computer and imaging scientists who have been active in digital imagery research with a particular group of end users, namely research scholars in the visual arts, including art and architecture historians, art curators, conservators, and scholars and practitioners in closely related disciplines. The workshop was structured as a series of breakout brainstorming sessions, each followed by plenary reports and discussion. The first two sessions were open to all topics in hopes of defining the scope of the workshop considerations, the next three were aimed at several aspects of digital imagery, and the last was focused on four common-interest topics that had emerged during the workshop. Individual presentations were made before and after these sessions.

Throughout the workshop, as a group we explored the potential of digital imagery for research in art and architectural history, conservation, and closely related fields, attempted to identify areas in which the research needs of digital imaging scientists and research scholars in the visual arts overlap in productive ways, and searched for genuinely collaborative projects to recommend for potential joint funding by the Andrew W. Mellon and National Science Foundations. The sessions were lively and productive. Participants learned a great deal from each other, discovering previously unfamiliar terms, concepts, and research practices. We faced the challenge of formulating truly collaborative projects, which would meet the research needs of both art historians and computer scientists. We did identify and explore a few major problem areas where serious progress would seem to require collaborative research by scholars in the visual arts and computer scientists at all stages of the projects. We also identified areas in which the digital imaging needs of research scholars in the visual arts, although perhaps not of serious research interest to computer scientists, might possibly be met by computer companies, or by programming support by Computer Science graduate students or interns. The collegial sharing of ideas at this workshop and the lines of communication opened especially between imaging scientists and art and architectural historians, curators, conservators, and scholars in closely related fields should help to advance future work in this field.

Relations Between Art History and Computer Science

At various times throughout the workshop we discussed the difficulty of formulating truly collaborative projects, which would meet the research interests of both information technologists and art and architectural historians, art curators, conservators, and scholars and practitioners in closely related disciplines. Although a few such projects already exist and provide excellent models, in general art historians and scholars in related fields have not worked with computer scientists, and differences in background, goals and research procedures make projects that are truly joint and collaborative relatively scarce.

We discussed various reasons for this lack of collaboration. At times we had difficulty understanding each other because of basic differences in terminology (e.g., we use terms

such as "metadata" and "content" in different ways), and lack of familiarity with fundamental domain-specific research concepts and methods. With few notable exceptions, most significantly in the fields of technical examinations, conservation and archeology, research scholars in the visual arts are unfamiliar with the basic principles of computer technology and the potential of digital imagery for research, while computer scientists are equally unfamiliar with the basic content of the humanities and the types of questions important to research of cultural heritage.

One of the central problems we discussed was a fundamental difference in research problems and procedures. Computer scientists traditionally seem most interested in larger, theoretical issues, aiming their research at achieving a proof-of-concept, whereas art historians, etc. usually have more specific, practical needs, which are nevertheless essential to their research. Although participants in the workshop enjoyed open, collegial, genuinely friendly exchange throughout, it was recognized that there is at present a divide between our disciplinary cultures that inhibits interaction and collaboration.

We do not see a quick fix to this complex problem. The resolution appears to us to require long-term efforts, including interdisciplinary curricular changes, such as the introduction of technical training in art history, and of humanities research projects in computer science, the collaboration of graduate students and interns, and the support of joint projects, as envisioned by the Andrew W. Mellon and National Science Foundations. We are convinced that cross-disciplinary education and collaborative projects offer great promise for innovative, productive projects in the currently fragmented world of research.

Research Needs

As a basis for exploring possible collaborative research, the group reviewed the image research needs of art and architectural historians, art curators, conservators, and scholars and practitioners in closely related disciplines. It was noted that such research takes place at many different levels, from beginning student projects through advanced courses and graduate theses to the most advanced professional research, and that these different levels have different needs. Various speakers sought to emphasize the essential need, for researchers at all levels, to have easy access to hundreds of thousands of basic images.

The interrelationship between research and teaching was discussed. Some participants felt that there was a canon of roughly two hundred thousand works of art that are touched upon in most art history curricula, for which a common body of basic images would suffice. Others emphasized the considerable expansion of the field of art history into areas such as everyday objects, tribal art and ceremony, and the now common practice of involving even introductory students in research projects requiring a variety of images (different views, details etc.) for whatever art they are assigned.

We noted also the contrast between carefully controlled, in-house imagery (e.g., in conservation laboratories) and the more common research imaging that takes place “in

the field", usually under conditions that are less controllable. Again we felt that improvements in both these areas should proceed at the same time; but several participants emphasized that the needs of the researcher in the field (e.g., studying an archaeological site or a private collection under serious practical constraints) were paramount and were not being met by current imaging technology.

We noted the promise of collaborative environments for research by students and professionals at different institutions, the current constraints of bandwidth and user interfaces, and the potential of Internet2.

The Need for Images

In the fields of art and architectural history, conservation, etc., physical objects provide the essential subject of study. Images of these objects are essential. At the same time, we understand these objects and their images in context, normally provided through analysis and commentary. Therefore, throughout the workshop, while retaining our focus on images, we discussed the importance of linking images to corresponding metadata, including text, sound, and even touch.

We distinguished among three categories of digital images used by research scholars in the visual arts. First, digital images taken under good conditions with normal viewing. Second, digital images taken in ways that are difficult or impossible with normal viewing. Third, newly constructed digital images, usually diagrammatic, to assist in studying works of art and architecture. The overwhelming majority of images studied by art historians fall in the first category and are therefore of primary importance for research in the cultural heritage field. On the other hand, the most productive research developments in the use of digital images of art and architecture have come in the other two categories, especially in the fields of technical examinations, conservation and archaeology.

Scientifically Accurate Color

At present high quality digital imaging of art requires huge amounts of human labor devoted to color correction in digital image processing and the endless need for calibration of monitors and printers to provide viewers with color similar to that in the original work of art. Extensive research has been underway for some time aimed at providing more scientifically accurate digital representations of color and other spectral qualities of art. Workshop participants applaud these projects and feel that more extensive research should be supported in this important area.

Image Science Research Dependent on Large Image Archives

Some imaging science research depends on the availability of large archives of digital images, large test-beds of content before significant research can be conducted. For some of this research, especially where dealing with the visual arts, these images must be of

high quality. In such cases, imaging scientists and research scholars in the visual arts have corresponding needs for large archives of high quality digital images of art.

Digital Capture of Images

Workshop participants spent considerable time discussing the primary job of digitally capturing images of art and architecture. Although high-level research requires study of the original object, we recognized that most research in these disciplines depends on study of photographs of art. We noted that much of the world's art has never been photographed, let alone digitized, and that art that has never had a public function or display is frequently not photographed. Moreover, only selective views have been taken of most sculpture and architecture. Only a negligible percentage of the millions of existing photographs have been scanned. Therefore, immense campaigns of digital imaging is the major need of art historical research at this stage. The rapidly increasing rate of decay of artifacts and architecture in situ and the danger of military and ethnic destruction give special urgency to this task. The advent of automatic digital acquisition and digital search promise a vast increase in information and accessibility.

Several participants called into question the idea that a single canonical image of any work of art would be adequate for even the most introductory research. Research photographs taken by scholars or under their direction are more accurate and more informative than standard commercial photographs, recording knowledgeable choice about, for example, the most informative views of sculpture and architecture, and avoiding, for example, excessively wide-angle lenses and overly dramatic lighting. Ultimately, the final use, which an image is to serve, should determine how it should be recorded.

In view of the need for massive, currently labor-intensive, campaigns for capturing digital images, one challenge for computer scientists would be to develop automatic recording techniques that also provide technical and informational metadata needed for most research on the vast range of types of art and architecture. We noted that, to some extent, specialized research purposes are at odds with the desire for automatic digital recording of art, without human intervention. Moreover, the amount of manual intervention currently needed for digital images of art, especially for accurate color, makes automatic digital capture for high-end research problematic. Ideally, researchers want control of the image on their computer screens, and to be free of the selective imaging decisions of others.

Smart Cameras and Image Trails

In order to use digital images as evidence, researchers need to know the conditions under which each image was made. The development of smart digital cameras that automatically record the lens, exposure, and other settings of the camera, as well as the context (e.g. date, color, temperature, type of lighting), would partially satisfy this need. However, in addition to digitally capturing these image parameters, the camera should

ideally be able to represent the object's exact measurements, its depth, and any other characteristic features such as its texture and feel.

In-house and In-field Digital Imaging

These requirements for research images of art and architecture need to be available not only for in-house images made under controlled laboratory conditions but also for researchers in the field, where conditions are not ideal and where equipment must be relatively small, light weight, inexpensive, and easily maintainable.

Types of Art and Aspects Needed for Research

The art historians present called attention to the immense variety in the types of art around the world and the different aspects that researchers need to study. In addition to relatively flat drawings, paintings, prints etc., there are three-dimensional sculptures of all sorts, some including moving parts, objects of industrial design from small to large scale, clothing meant to be seen as worn and in motion, and installation art in which the environment is part of the work and needs to be recorded. Video recording is necessary, moreover, for the field of performance art. Most dramatically, there is architecture and landscape design whose appearance changes at different times of day and under different weather condition, and where one must study interior as well as exterior spaces. For all of these we need overall views and details taken at different angles under alternative lighting conditions, recording evidence not only of form but also of texture, color, reflectance, and in some cases such things as feel and temperature. The advent of digital video has called attention to how inadequate still photography is for recording much of the world's art. Remarkably, the ability of laser technology to make highly accurate and detailed reproductions of three-dimensional objects has dramatically transformed the availability of evidence for studying artifacts at a distance. Given this nearly infinite range, a major concern is for informed selectivity by end users of the works of art and the types of photographs that would prove most useful for study.

During the workshop, we only briefly discussed scanning existing photographs of art. On the one hand we noted that existing image collections provide important historical records of the appearance and conditions of art at earlier times, including objects that have deteriorated or changed in other ways, or were even destroyed. On the other hand, we observed that new digital imaging could usually be of significantly higher quality, with the opportunity of recording the conditions and context under which the images were acquired. Both existing collections and new ones are important for research.

Virtual Reality and Virtual Reconstruction

Virtual reality and virtual reconstruction techniques have produced intriguing results in the creation of new, principally diagrammatic images. Most of this research has attempted the virtual reconstruction of individual buildings, archaeological sites, and even the design of entire cities. These digital projects not only convey an understanding of the form and appearance of altered or destroyed buildings, but also open the focus for

new research, forcing consideration of alternative designs, looking for new evidence, determining how the parts of a building might have fit together and how they might have been seen and used. Some virtual reconstructions infer three-dimensional models from two-dimensional photographs; others apply information from photographs on top of three-dimensional models to create realistic models.

Image Search by Visual Characteristics

A major area of research with tremendous promise is image search by visual characteristics. During the workshop, this emerged as one of the most prominent areas in which the research interests of both computer scientists and art historians are aligned and an area in which collaboration is essential. Alternative approaches were described for addressing image search issues; and many are promising. Nevertheless, many end users present felt that the approaches currently pursued in computer science research appear to be overly general and may not meet the specific research needs of art historians and others. Most art historians search for specific things in a limited body of material (e.g., all inscriptions on nineteenth century French paintings; a specific saint in Italian Renaissance sculpture; paint remains on ancient Egyptian architecture; a specific abstract configuration in twentieth century American prints). Many felt that specifying an image search in this way should greatly reduce the difficulty of the search procedure. Participants were unable to think of more than a few rare instances where end users might wish to search vast storehouses of images for a certain color or shape even within the field of art. Moreover, the differences among types of images (e.g., photographs of the natural world vs. photographs of works of art; photographs of small two-dimensional art vs. large three-dimensional art and architecture; photographs of representational art vs. non-representational or abstract art) make searches of huge bodies of unclassified images unfruitful. It was also pointed out that human observation of two-dimensional images is informed by three-dimensional knowledge (e.g., the arm and leg projecting from behind a wall indicates the presence of the rest of the person behind; the rectangular shape of a building indicates the presence of an entire three-dimensional building), whereas computers see only two-dimensional images of the details included. For these reasons, many felt that image search by visual characteristics would be most successful with specialized tagging, or mark-up, by end users rather than automatically. Participants felt that this was one of the key areas for research and that the most useful results could only be produced through collaborative efforts involving both end users and computer scientists.

Reference Database for Images

There is need for the development of a reference database of images to stimulate the creation of benchmarks for searching algorithms and other tools as they are developed by computer scientists.

Combining Text and Visual Characteristics in Image Search

There seemed unanimous agreement that image search would be most successful when linked to corresponding text, ideally also incorporating sound, and any other characteristics desired such as feel.

Metadata for Images

Search capability is such a transforming function of computer technology that it makes relevant nearly all images that are not themselves digital (e.g., all pre- and non-digital images of art, including technical images of art works such as x-radiographs), because once scanned they can be searched. Given the nature of works of art, some end users argued that most art history searches would always be most efficient when aided by encoded metadata, even if search by visual characteristics became useable. Thus by systematically tagging images, experts over time would provide the means of precise searches of works of art for all future users of those images. Each disciplinary specialty (e.g., photography conservation, structural engineering) would of course have to establish its own metadata standards. Because analytical encoding is such a labor-intensive activity, the desirability of automatic generation of metadata was raised, and while research progress is continually being made in this challenging area, it will be some time before computers can extract and transform image information into text.

As before, there seemed unanimous agreement that there should be information fusion, putting together text, image, sound, and other relevant data into easily accessible digital libraries. Among these less obvious types of perception, touch received occasional attention. Because touch is such an important way to understand certain aspects of art (e.g., the process of creation, conservation, the feel of the form and surface of sculpture), the ability to examine virtual information about or reproductions of art through touch and the option of including touch interfaces in information searches were recommended for development.

Analyzing and Manipulating Images

Much of the potential of digital images for research in art and architectural history, conservation, etc. derives from new means of analyzing and manipulating digital images. Although most of these processes have pre-digital prototypes, the vastly increased ease and speed made possible by digital technology has moved these processes into the mainstream. A key point here, emphasized by many participants, is that researchers themselves must have direct access to these modes of analysis and manipulation for uninhibited scholarly exploration. This means that research scholars, non-computer specialists, will require training to understand and take advantage of the digital advances aiding their work. For this end, the gradually increasing number of model projects, demonstrating the scholarly revelations achieved by means of these developments, are providing a healthy stimulus.

Types of analysis and manipulation that have already produced important new research results include many that parallel how we look at art under normal conditions (e.g., zooming in on details, moving around an object, moving light over an object, separating and reassembling objects). But there are also new types of analysis and manipulation that expand the usefulness of technical imagery (e.g., zooming into highly magnified details, mosaicing infra-red reflectograms, superimposing states of prints or various types of technical images of the same painting, varying the intensity of these layers or coloring them differently so that differences are clear, superimposing photographs of buildings on VR models, overlaying alternative reconstructions of archaeological sites onto photographs of the sites as they exist today). The computer scientists cautioned that researchers must understand these processes of analysis and manipulation to know exactly how they are manipulating the images, how they are changing the original images. Proprietary software that conceals the nature of automated manipulations from end-users makes reliable analysis difficult, sometimes impossible. The computer scientists cautioned that researchers must understand these processes of analysis and manipulation to know exactly how they are manipulating the images, how they are changing the original images.

Infrastructure and Interfaces

A basic problem for digital image research in art history and related fields is the lack of an institutional "interface," an academic infrastructure that allows researchers in the arts to communicate with computer scientists, to integrate differing software systems such as Mac and Linux to serve the purpose of joint research projects. This lack of a common or compatible infrastructure stands in the way of individual and collaborative research in the cultural heritage field itself and, even more so, is a major impediment to collaborative research between art historians etc. and computer scientists. Participants acknowledged the need for computer operating systems and software that allowed for effective user interfaces.

For optimal research of works of art, we need to link the rapidly growing collections of art images and texts so that users can search and access images and associated metadata across all relevant collections. Ideally, we need common, comprehensive, coherent digital resources.

Viewing

A weak link in most art historical research using high quality digital images is the size, resolution, and color accuracy of monitors. Most institutions provide only single, moderate quality monitors and projectors for students and faculty, since priority is nearly always given to speed and the viewing of text. Study of high quality digital images of art and architecture benefits greatly from the availability of workstations with several large monitors or projectors, side by side, adjusted for high resolution and maximum number of colors. Institutions should be urged to set up occasional study stations of this sort for research and the serious study of art and other subjects dependent on accurate, high-quality imaging. Certain types of research and study benefit from the availability of large

screen projection, which allows viewers to experience viewing large-scale sculpture or architecture or movement through architectural space. We encourage research in color accuracy, high resolution, adjustments for ambient light, and other aspects of digital viewing and we look forward to advances that will make large, high-resolution monitors available at reasonable cost.

Major Issues not Specific to Images

There are a number of issues of overriding importance that we discussed only occasionally, because they are no more relevant to images than to any other type of digital information, and because they are already, quite properly, well funded and the subject of focused conferences around the world. Nevertheless, we discussed issues of copyright and bandwidth, the importance of implementing research prototypes, and the need for introducing computer research into the curriculum at all levels. In particular, we frequently discussed digital longevity, storage, the preservation of digital images, and the tools for accessing them.

Recommendations

I. Areas requiring extensive, on-going interdisciplinary collaboration of imaging scientists with research scholars in the visual arts.

For joint funding by the Andrew W. Mellon and National Science foundations, we recommend well formulated projects and additional workshops focused on the following primary areas, where collaboration between art historians, art curators, conservators, and scholars and practitioners in related fields and computer and imaging scientists promises important advances for research in art and architectural history, conservation, archaeology, and other related disciplines.

A. Research into means of conducting image search by visual characteristics should be pursued aggressively. Computer and imaging scientists should work closely with research scholars in the visual arts at all stages of this research so that the procedures developed meet the types of search needs that would be useful in cultural heritage fields. A reference set of images should be developed to stimulate the creation of benchmarks for image search. Search by image characteristics should be integrated with search by text, sound, and other useful features.
B. Systematic text metadata should be created for all images to facilitate administration and search of the images. Given the diversity of types of art and architecture etc., the creation of metadata standards within each art history specialty should be explored. Text metadata should be merged with images, sound, and other features. Given the labor-intensive nature of encoding, ways to automate this process wherever possible should be explored.
C. The impressive achievements of three-dimensional modeling of sculpture, individual buildings, architectural complexes, archaeological sites, and cities

should be greatly expanded. Procedures should be developed to facilitate the merging of the currently separate techniques of CAD and Virtual Reality modeling.

D. An infrastructure should be created so that all aspects of research using digital images of art and architecture are integrated, allowing image search across all relevant image and text databases, and allowing joint projects with scholars in different disciplines and at different institutions. Interfaces should be created so that researchers can explore any software, modules, plug-ins, etc. and link those that would be of use in any given research project. All of these computer aids should be transparent and easy to learn so that they can be used inventively and with confidence by researchers.

II. Areas of importance for research in the visual arts but requiring more limited, practical solutions by imaging scientists, information specialists, and imaging industries.

We recommend that computer companies be urged to develop some of the following imaging equipment; that computer science departments be encouraged to take on some of these needs as projects for graduate students and interns; and that information specialists be asked to work under the guidance of art historians, etc. to satisfy some of these highly specialized research needs. To achieve these goals, we recommend that the Andrew W. Mellon and National Science Foundations fund initiatives to improve direct communication between specialists in the two fields, and support the creation of an ad-hoc podium for communication between the art historians, etc., and representatives from the imaging industries.

A. Smart cameras should be developed that automatically record not only the date and time, but also the camera, lens, and as many as possible of the camera settings and the physical environment in which each digital image is made.
B. Inexpensive, lightweight, easily repaired laser scanners; remote sensors, etc. should be developed for recording in the field. It would be ideal if all of these recording techniques were incorporated in a single piece of equipment that could be carried by a single researcher, as in a camera case.
C. In addition to the more important campaigns of new digital photography carried out by informed subject matter specialists, described below, efforts should be made to develop automatic recording procedures for some uses.
D. Procedures for creating detailed, accurate models of three-dimensional objects using laser scanning should be further developed.
E. Procedures should be developed so that a textual trail is created for each digital image, automatically recording every change to each image.
F. Automatic technique for stitching together multiple sections of an image into a larger assembly should be perfected, insuring better alignment and uniformity, preferably through development of plug-ins for off-the-shelf software such as Adobe Photoshop.

G. Superimposition of photographs, sometimes made with different image modes should be perfected with better alignment, again through development of plug-ins for off-the-shelf software such as Adobe Photoshop.
H. Convenient procedures should be developed so that students and research scholars can easily analyze and manipulate images to explore different aspects of art and architecture. These digital processes should be transparent so that the results can be fully understood and used reliably as evidence.
I. Comprehensive databases of art images and texts should be created that can be linked, searched, and accessed by many users.
J. Using Internet2, efforts should be supported that facilitate the creation of collaborative environments.

III. Areas of importance for research in art history and closely related disciplines but requiring little involvement of imaging scientists.

We strongly recommended major funding by the Andrew W. Mellon Foundation and other foundations in the following areas. These are the basic preconditions for all large-scale advances in research in art and other disciplines studying digital photographs of the world's cultural heritage and are necessary for some types of research by computer and imaging scientists.

A. Major campaigns should be undertaken of new digital photography of the full range of the world's art and architecture, selected by scholar-teachers who carry out research not only in traditional survey course areas but also in the vastly expanding fields of indigenous art, industrial design, etc. For performance art, architecture and sculpture, digital video should be used in addition to still cameras.
B. A separate extensive campaign of new digital photography should be conducted of selected monuments, recording multiple views and details as well as different aspects of art digitally captured under various conditions. Where instructive, digital images employing infrared, ultraviolet, and other forms of technical lighting should be used. Digital video, laser scans, and other forms of recording should be included. The works to be photographed should again be selected by scholar-teachers and should span the full range of the world's art.
C. Major campaigns should be conducted scanning important existing photographic collections of the world's art, including technical documentation of art works such as infra-red reflectograms and x-radiographs. These campaigns should include scholars' personal research archives where these have been taken by the scholars in areas of their expertise and are of high quality.
D. Important books and articles in the fields of art history etc. should be scanned.
E. With all of the photographic and scanning campaigns listed above, extensive evidence of the camera and settings, etc. and the conditions under which photographed should be recorded automatically. Extensive metadata should accompany each digital image to allow for comprehensive searching.

F. Provision should be made for an on-going process of digital scholarly encoding of digital images of art. Encoded images should be searchable by artist, art historians, date, subject, concept, technique, motif, etc.

IV. Areas of importance for research in the visual arts, requiring extensive, continuing research by imaging scientist, but little involvement of research scholars in the visual arts.

We recommend that current efforts to develop more scientifically accurate digital representations of color and other spectral qualities of art be supported along with other promising initiatives in this essential area.

V. Other recommendations

Colleges and universities should be encouraged to incorporate computer imaging problems in art history and other curricula in the humanities. Computer Science and Engineering departments should be encouraged to incorporate in their curricula imaging problems of use to research scholars in the visual arts. Initiatives that stimulate and facilitate scholars in art history and closely related disciplines to become and remain informed about developments in the use of digital imaging in other fields should be supported.

Appendix 1: Program

Digital Imagery for Works of Art

Harvard University Art Museums
Cambridge, Massachusetts
November 19 and 20, 2001

Monday, November 19, 2001

10:00 - 11:00 Tours of the Straus Center for Conservation and the Digital Imaging and Photography Department.

11:30 - 12:00 Registration

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Opening session, chair: Ron Spronk

12:00 - 1:00 Working lunch

12:45 - 1:00 Welcome, Introductory talks
-James Cuno, Elizabeth and John Moors Cabot Director, Harvard University Art Museums
-Kevin Kiernan, Professor of English, University of Kentucky, Lexington; Director, Electronic Beowulf Project
-Charles Rhyne, Professor Emeritus, Reed College, Portland OR
-Ron Spronk, Associate Curator for Research, Straus Center for Conservation, Harvard University Art Museums

1:00 - 1:30 "Cooperative Research and User Needs." *Charles Rhyne*

1:30 - 2:15 Break out sessions, four groups, open session

2:15 - 3:00 Break out groups report back and discussion

3:00 - 3:15 Break

3:15 - 4:00 Break out sessions, four groups, open session

4:00 - 4:45 Break out groups report back and discussion

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November 19, 2001, Evening program (Adolphus Busch Hall)

6:30 - 7:00 Cocktails

7:00 - 9:00 Dinner

8:15 - 8:45 "Creating and Managing Digital Images: Individual and Collaborative Efforts at Harvard's Fine Arts Library and Art Museums." *Richard Benefield, Associate Director, Harvard University Art Museums*

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Tuesday, November 20, 2001

Session II: Image capture, processing and analysis, chair: Kevin Kiernan

8:30 - 8:45 Coffee

8:45 - 9:15 "Digital Imaging and Technical Art History: From Old Masters to Piet Mondrian." *Ron Spronk*

9:15 - 10:00 Break out sessions, four groups

10:00 - 10:45 Break out groups report back

10:45 - 11.15 "Image Searching: What you see is what you get, but not what you want." *Michael Lesk*, Division Director, Information and Intelligent Systems, National Science Foundation.

11:15 - 11:30 Break

11:30 - 12:15 Break out sessions, four groups

12:15 - 1:00 Break out groups report back and discussion

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Session III: Image storage and access, and improved user interfaces, chair: Charles Rhyne

1:00 - 2:30 Working lunch

2:00 - 2:30 "Collaboration and the Need for Useful and Useable Interfaces." *Kevin Kiernan*

2:30 - 3:15 Break out sessions, four groups

3:15 - 4:00 Break out groups report back and discussion

4:00 - 4:30 "Towards a joint grant program for the Digital Imaging of Works of Art for the Andrew W. Mellon Foundation and the National Science Foundation." *Donald J. Waters, Program Officer, Scholarly Communications, The Andrew W. Mellon Foundation, and Stephen M. Griffin, Program Director, Special Projects Program, National Science Foundation.*

4:30 - 5:00 Discussion and closing comments

Wednesday, November 21, 2001

10:00 - 11:00 Tours of the Straus Center for Conservation and the Digital Imaging and Photography Department.

Appendix 2: Attendees

Digital Imagery for Works of Art

Harvard University Art Museums
Cambridge, Massachusetts
November 19 and 20, 2001

For the National Science Foundation:

Kirk Alexander - Princeton University
Peter Allen - Columbia University
Roy Berns - Rochester Institute of Technology
Edward Chang - University of California at Santa Barbara
David Cooper - Brown University
Bob Englund – University of California at Los Angeles
Michael Ester- Luna Imaging, Inc.
Franziska Frey - Rochester Institute of Technology
Stephen Griffin - National Science Foundation
Corinne Jörgensen - State University of New York at Buffalo
Kevin Kiernan - University of Kentucky
Michael Lesk - National Science Foundation
Chung-Sheng Li - IBM T. J. Watson Research Center
Worthy Martin - University of Virginia
Brent Seales - University of Kentucky
James Wang - Pennsylvania State University

For the Andrew W. Mellon Foundation:

Jim Coddington - Museum of Modern Art, New York
Sarah Fraser - Northwestern University
George Fifield - Boston Cyberarts Festival
Bob Futernick - Fine Arts Museums of San Francisco
Bernard Frischer - University of California at Los Angeles, Cultural VR Lab
Henry Lie - Harvard University Art Museums, Straus Center for Conservation
Kirk Martini - University of Virginia
Paul Messier - Boston Art Conservation
Sam Quigley - Harvard University Art Museums
Charles Rhyne - Reed College
Angelica Zander Rudenstine - Andrew W. Mellon Foundation
John Shearman - Harvard University
Ron Spronk - Harvard University Art Museums, Straus Center for Conservation
Jill Sterrett - San Francisco Museum of Modern Art
Donald J. Waters - Andrew W. Mellon Foundation